3D Printing Millimeter-Wave Lens with Scanning Beams

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***Abstract*—High-gain beam-scanning antennas are very important in millimeter-wave (MMW) and terahertz (THz) applications. Dielectric lens is a good candidate for this purpose because it has no metal or feeding loss. In this work, a discrete dielectric lens with an antireflection layer is studied. A new method is proposed to realize beam-scanning properties in MMW region. The design concept is applicable to other frequency ranges as well. Three-dimensional (3D) printing technology is employed to simplify the manufacturing process, and to reduce the fabrication cost. Experimental results in MMW regions verified the concept of lens design.**

Keywords—Beam scanning; Lens antennas; 3D printing

I. INTRODUCTION

Millimeter wave (MMW) technology has been one of the fastest growing subdisciplines because of many potential applications in radar, imaging, detecting and high-speed communication. In these systems, antennas are one of the fundamental components. However, the feeding loss, conductor loss and fabrication accuracy will prevent most types of microwave antennas from being scaled up to MMW region, especially for high-gain applications.

Lens and reflectarrays are very similar in design and operation principles, which transform the spherical wavefronts into the planar ones in the far-field distance. Compared with the reflectarray, lens could eliminate the blockage caused by the feeding antenna. Therefore, the lens installation and measurement are more flexible [1]. However, two shortcomings are inherent in the lens, i.e., reflection at the interface between air and lens surfaces as well as lack of beam-scanning ability. Generally, an antireflection (AR) coating layer is added at the interface [2], however, which makes the fabrication more complex. On the other hand, beam-scanning ability is very important in MMW technology. Unfortunately, no phase shifters are available in those frequency bands, and hence beam-scanning lenses are scarcely reported in MMW band. In this work, a lens with a periodically structured AR coating and beam-scanning properties is presented. Three-dimensional (3-D) printer is utilized to fabricate the lens, which can simplify the fabrication process and reduce the cost.

II. BEAM SCANNING LENS

Fig. 1 illustrates the schematic of lens elements. Fig. 1(a) is the lens element without AR coating, which is a square dielectric slab with height *h* and width *w*. Fig. 1 (b) is the lens element with AR coating. The element is a square hole defined by height *t* and width *g* introduced in the dielectric slab. The dielectric has a relative permittivity $\varepsilon_r = 2.95$ and loss tangent tan δ=0.01 at 60 GHz ($\varepsilon_r = 2.9$ and tan δ=0.025 at 300 GHz).

Fig. 2 shows the reflection and transmission coefficients of the lens elements at 300 GHz versus element height. Without AR coating, the element transmission coefficient declines as the dielectric height increases, due to the dielectric and reflection loss. The dielectric loss cannot be eliminated because of the lossy nature of the dielectric, but the reflection coefficient can be reduced by adding a quarter-wave AR coating at the interface of air and dielectric. The results are scalable to 60GHz.

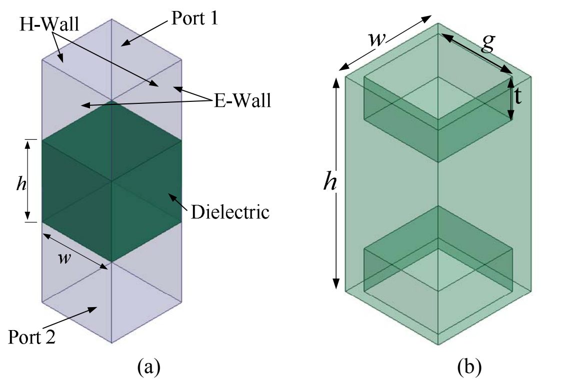

Fig. 1. Schematic model of lens phasing elements. (a) Without AR coating. (b) With periodic-structure AR coating.

III. RESULTS

In this design, the beam is expected to scan within an angular range of over 20^o in a frequency band from 50 to 70GHz. The beams are located at -30^o, -25^o, -20^o, -15^o, and -10^o, at 50, 55, 60, 65 and 70 GHz, respectively. In the design,

multiple frequency phase matching method is employed [3]. The designed lens has a square aperture with 21 × 21 dielectric elements to provide the necessary phase shift. Fig. 3 (a) shows the simulation model of the lens. The lens with a fixture is fabricated by a 3D printer having a resolution of 25 µm, and the fabricated prototype is shown in Fig. 8 (b). An open-ended waveguide is utilized to feed the lens. Simulated and experimental results are shown in Fig. 8 (c), which reveals the beam-scanning ability of the lens. The simulated and measured radiation beams have a little deviation from the designed positions, owing to the phase error between the desired and achieved phase by varying the element height, but the deviations are less than 2^o at all frequencies. The simulated side lobe levels are below -8dB, and the measured values are slightly higher due to the introduced errors in reflection phase, fabrication and measurements.

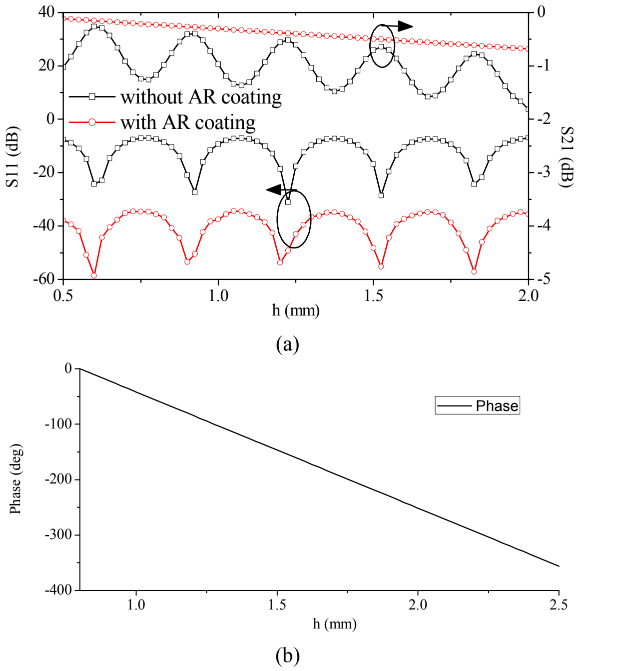

Fig. 2. (a) Transmission and reflection coefficients of the lens elements with and without AR coating at 300 GHz. (b) Transmission phase of the lens elements with AR coating versus h.

CONCLUSION

A frequency scanning dielectric lens antennas has been demonstrated in millimeter-wave frequency. A scanning range of 20^o from 50 to 70 GHz is achieved. Reflection at the air-dielectric interface is minimized by an AR layer in the form of a quarter-wave transformer. The prototype is effectively fabricated using 3D printing technology.

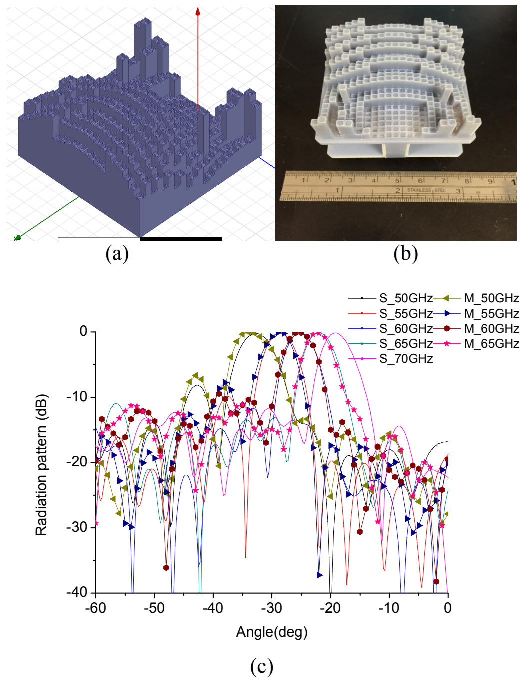

Fig. 3. (a) Model, (b) picture of the beam scanning lens at 60 GHz and (c) measured and simulated radiation patterns at 50, 55, 60, 65 and 70GHz. Measured results at 70 GHz is not given, because the measured system only can cover 50 ~ 67 GHz. The beam direction is -34, -29, -25, -22, -19deg, respectively.

ACKNOWLEDGMENT

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